TIMBER PILES RETROFITTED WITH FIBER REINFORCED POLYMERS

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ABSTRACT

The description of the experimental work carried on in order to estimate the structural behavior of timber piles retrofitted using fiber reinforced polymers (FRP) is undertaken in this paper. Sixteen specimens were tested under eccentric compressive loading. Each specimen was tested first in its unretrofitted condition, then cut and connected using the proposed FRP retrofit technique, and retested. The results show that the retrofitted specimens are capable of reaching same or higher strengths than that of the unretrofitted specimens with minimal reduction in their stiffness.

RESUMEN

En este artículo se describe el trabajo experimental llevado a cabo para estimar el comportamiento estructural de pilotes de madera reforzados usando polímeros reforzados con fibras (FRP). Dieciséis especímenes fueros ensayados bajo carga excéntrica a compresión. Cada espécimen fue ensayado primero en su condición no reforzada, luego cortado y conectado usando la técnica propuesta de reforzamiento con FRP, y de nuevo vuelto a ensayar. Los resultados muestran que los especímenes reforzados son capaces de alcanzar la misma o más alta resistencia que la de los especímenes no reforzados, con una reducción mínima en su rigidez.

Key words: timber piles, eccentric loading, fiber-reinforced polymer (FRP)

1 INTRODUCTION

Experimental work is the key element to develop new knowledge. In this paper, the methodology followed to test alternative ways to retrofit timber piles subjected to flexo-compression is explained in detail. Note that this technique is proposed in cases where a portion of the pile is cut out and replaced with a new piece of timber. Usually, this new piece is connected to the existing pile by metal fasteners ([1], [2]). Even though these fasteners are capable of transmitting axial forces, they are not designed to transfer moment. This limitation could potentially cause severe consequences as in the case of a bridge collapse documented in

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references [3] and [4]. No studies, to the knowledge of the author, have been conducted previously to investigate the use of fiber reinforced polymers (FRPs) as the structural material capable to restore the flexural moment capacity in the timber pile subjected to combined flexure-compression [5].

This paper is based on the work already published by Caiza et al. (2012) [6]. It should also be noted that the experimental work explained in this paper was conducted under the support of the Illinois Department of Transportation and the University of Illinois at Urbana-Champaign.

2 PROPOSED RETROFIT TECHNIQUE

Figure 1 shows the retrofit technique whose experimental verification tests are explained in this paper. The first step is to align the timber post and the existing pile and connect them using a vertical steel drift pin at the center of the round pile. After the two spliced pieces of timber are attached, the round surface of the timber pile is sanded, and finally, the FRP sheets are applied around the pile with resin using the hand lay-up process. As an alternative, a thin mortar shell (less than 2 mm) could be applied to provide an evenly round surface for the FRP sheets. In addition, the connecting element could be a vertical steel drift pin or steel nails.

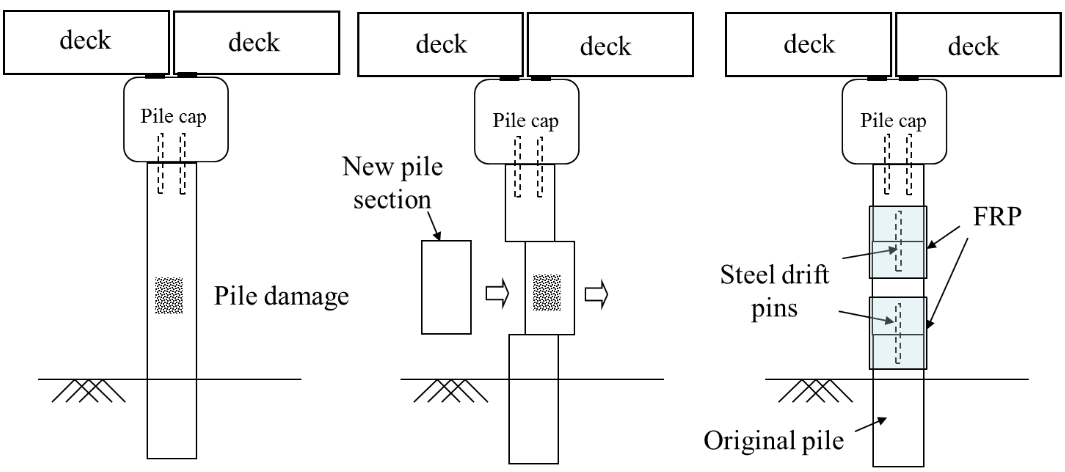


Figure 1. Proposed retrofit technique
(adapted from Caiza et al. 2012)

3 SPECIMENS DESCRIPTION

Sixteen specimens were prepared by cutting them from examples obtained from several bridges in the state of Illinois. The specimens had a constant length of 1220 mm, and their diameter varied between 249 mm and 318 mm. The wood was Northern and Southern Red Oak. A mortar shell was utilized in the retrofit of four specimens. A wedge was introduced in two of the tested specimens. Diagonally driven nails at the sides of the specimen were used in three specimens.

Table 1 summarizes properties and details of the materials used in retrofitting the specimens. Vinylester resin was used to form the matrix of both GFRP and CFRP. The glass fabric used was woven roving, and was selected for its relatively inexpensive, high impact, and high strength two-directional reinforcement properties. The carbon fabric used was plain weave, which is characterized with light-weight and high stiffness. The concrete mortar has a relatively high compressive strength of 22 MPa at 1 day, as well as a fast final set time of 2 hours. It comprises one component, microfiber, silica plus polymer mortar

Table 1. Properties of the materials used to retrofit the timber piles.

Material	Properties
Glass FRP	Modulus of elasticity =12400 MPa, thickness = 0.6 mm
Carbon FRP	Modulus of elasticity = 135800 MPa, thickness = 0.3 mm
Concrete mortar	Compressive strength (1 day) = 22 MPa, final set time of 2 hours.

4 TEST SET-UP

The timber piles were tested using a 2670 kN MTS uniaxial servo-controlled compression machine. The flexural moments were introduced thanks to a roller with an eccentricity of 76 mm from the centroidal axis of the pile specimen (see **Figure 2 a)**). The roller applied the eccentric compression force to a steel plate specially manufactured for these tests. There were two 38 mm thick steel plates bolted using ten 19x151 mm bolts for the top plate and eight 19x151 mm bolts for the bottom plate.

The instrumentation consisted on an internal load cell and an internal Linear Variable Differential Transducer (LVDT) to measure actuator position. In addition, two LVDTs were placed at the top and bottom of the pile specimen to monitor the relative displacement between the specimen and the end plates during testing (see **Figure 2 a)**). Finally, two vertical extensometers were placed at the mid-height of the specimen on two opposite sides to measure axial strains (see **Figure 2 b)**).

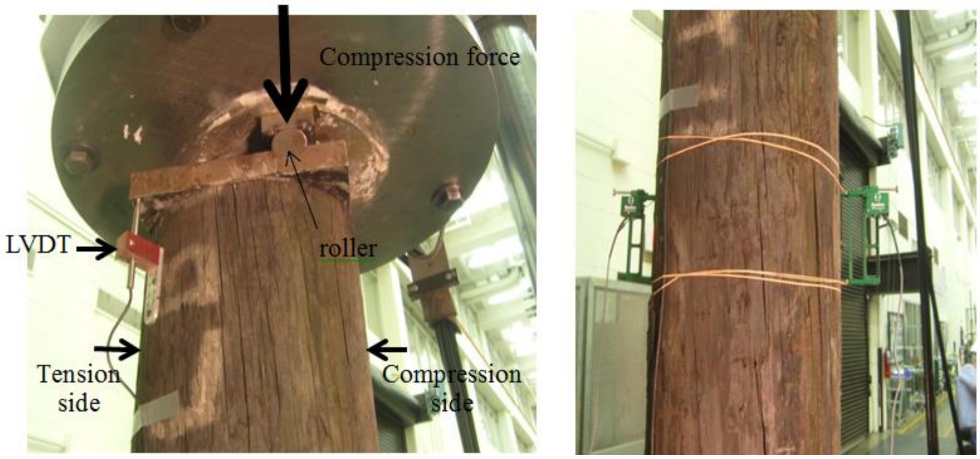


Figure 2. Instrumented specimen.
(adapted from Caiza et al. 2012)

5 EXPERIMENTAL RESULTS

First, an unretrofitted specimen was tested until a point where nonlinear behavior of the specimen was observed. Then, the specimen was cut to simulate a post connection, and retrofitted with a proper number of FRP wraps. The retrofitted specimen was then reloaded up to a point similar to the unretrofitted test.

The results of the flexure-compression tests of all 16 pile specimens are summarized in **Table 2**. The specimens were retrofitted: 1) with FRP sheets without mortar shell, 2) with FRP sheets and mortar shell, 3) with FRP sheets and mortar-filled wedges, and 4) with only FRP sheets but the pile was connected using nails. Note that the pile specimens in test groups 1), 2) and 3) were connected using steel drift pins. The second and third rows in each section of the table represent the maximum compression forces of the unretrofitted (P_{unret}) and retrofitted (P_{ret}) specimens, respectively. The fourth row presents the ratio between retrofitted and unretrofitted maximum forces.

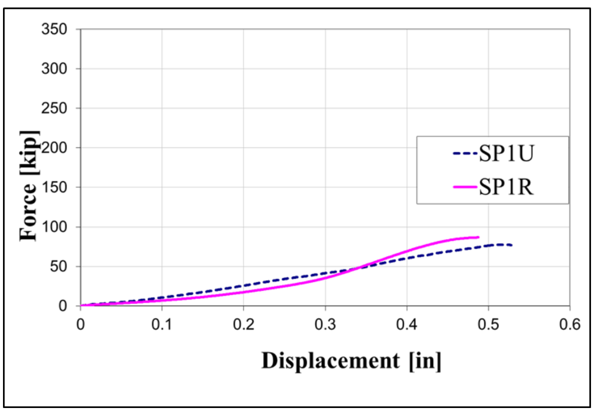
The maximum forces attained in the retrofitted tests were similar to or greater than those obtained from the unretrofitted specimens regardless of the retrofitting details, with the exceptions of specimen SP5 and SP13. SP5 had an uneven pile surface, which probably affected the perfect wrapping of the FRP sheets. An earlier crushing of the filling material in the wedge could explain SP13 weak resistance. In fact, the extremely small thickness of the CFRP jacket could not avoid the lateral expansion of the mortar in the wedge and its crushing. Further, the results shown in the table prove that using steel drift pins or nails results in similar performance, since the average P_{ret}/ P_{unret} ratio for these cases were 1.06 and 1.05, respectively.

Table 2. Maximum forces of unretrofitted and retrofitted specimens under flexure-compression tests.

Without mortar shell							
Specimen	**SP1**	**SP2**	**SP3**	**SP4**	**SP5**	**SP6**	**SP7**
P_{unret} [kN]	347	436	289	863	516	565	325
P_{ret} [kN]	387	529	329	912	467	565	3253
P_{ret}/P_{unret}	1.12	1.21	1.14	1.06	0.91	1.00	1.00
With mortar shell							
Specimen	**SP8**	**SP9**	**SP10**	**SP11**			
P_{unret} [kN]	1406	787	555	681			
P_{ret} [kN]	1397	778	681	810			
P_{ret}/P_{unret}	0.99	0.99	1.23	1.19			
With wedge							
Specimen	**SP12**	**SP13**					
P_{unret} [kN]	592	725					
P_{ret} [kN]	801	360					
P_{ret}/P_{unret}	1.35	0.50					
With Nails							
Specimen	**SP14**	**SP15**	**SP16**				
P_{unret} [kN]	302	498	632				
P_{ret} [kN]	351	498	623				
P_{ret}/P_{unret}	1.16	1.00	0.99				

Source: Caiza et al. (2012)

Figures 3, 4, 5, and 6 compare the curves force-displacement of the unretrofitted (U) and retrofitted ® specimens for the cases without mortar shell, with mortar shell, with wedge, and with nails, respectively. The forces and displacements were measured by the internal loading cell and LVDT, respectively.



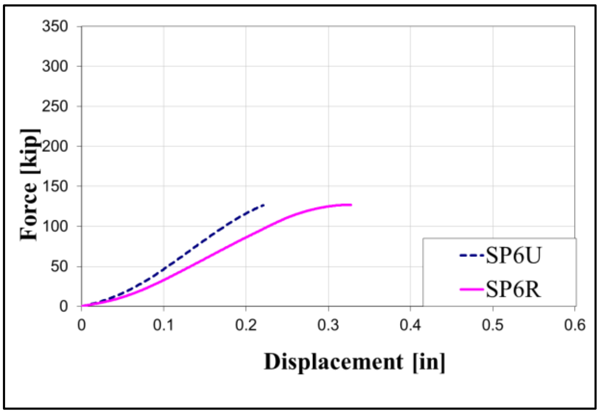


Figure 3. Force-displacement relationship for specimens without mortar shell

Figure 3 shows two specimens (SP1 and SP6) without mortar shell. The first interesting characteristic of these tests is their stiffness, which is very different beween them. This difference is explained on the different decay degree of the specimens. However, the unretrofitted specimens were always stiffer than the retrofitted specimens, except in a small displacement range between 0.35 and 0.5 in. (specimen SP1). In addition, the unretrofitted and retrofitted strength was almost the same for both specimens (SP1 and SP6).

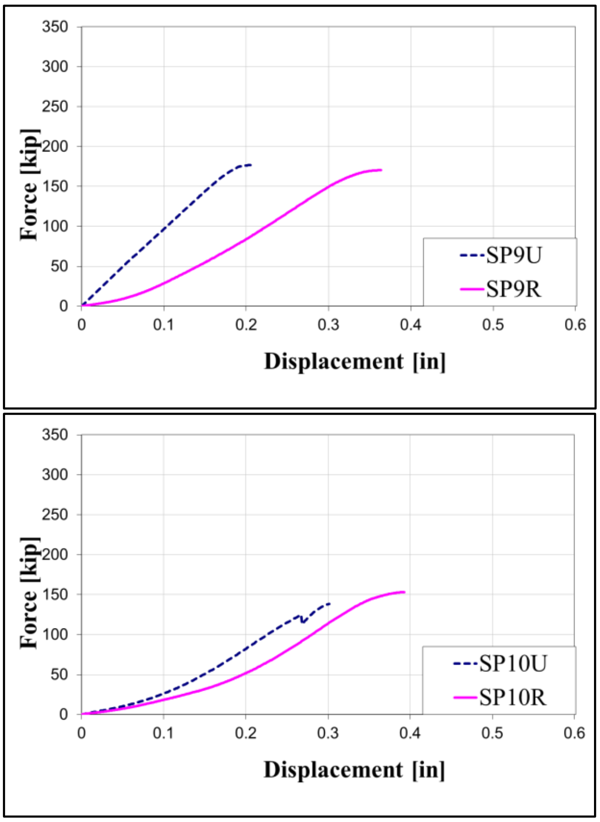


Figure 4. Force-displacement relationship for specimens with mortar shell.

Figure 4 shows two specimens (SP9 and SP10) with mortar shell. The retrofitted stiffness of both specimens is less than that of the unretrofitted specimen. However, the retrofitted specimens had higher strength. This is particularly clear in specimen SP10.

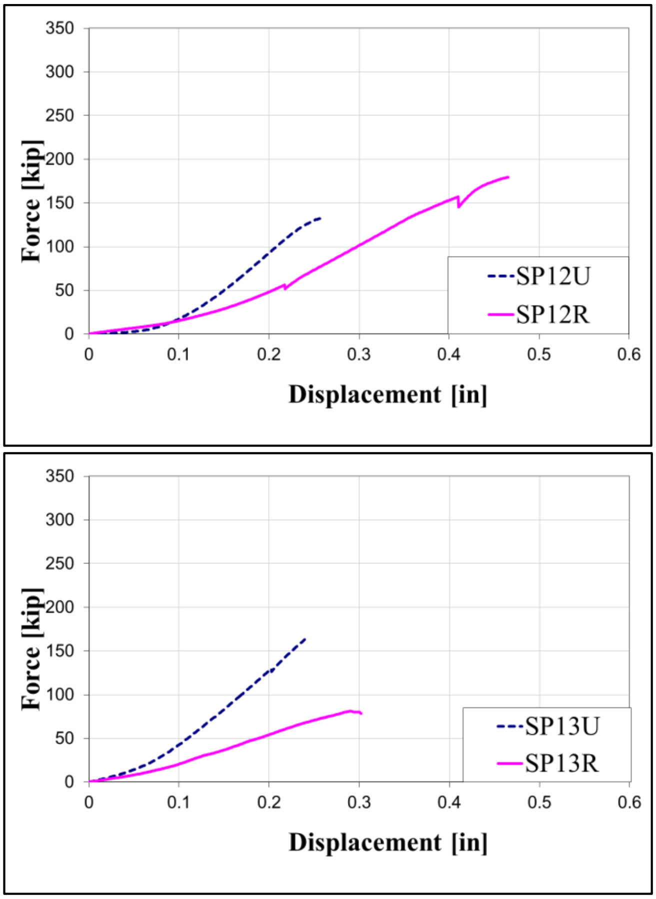


Figure 5. Force-displacement relationship for specimens with wedge

Figure 5 shows the two specimens (SP12 and SP13) with a wedge at the interface between the two pile portions separated by the cut. Specimen SP12 was GFRP retrofitted in contrast with specimen SP13, which was CFRP retrofitted. Specimen SP12R could reach relatively high strength, even though its stiffness was definitively lower than the unretrofitted case. In the case of specimen SP13, as explained in a previous section, the local failure of the wedge explicated the low strength and stiffness of the retrofitted specimen.

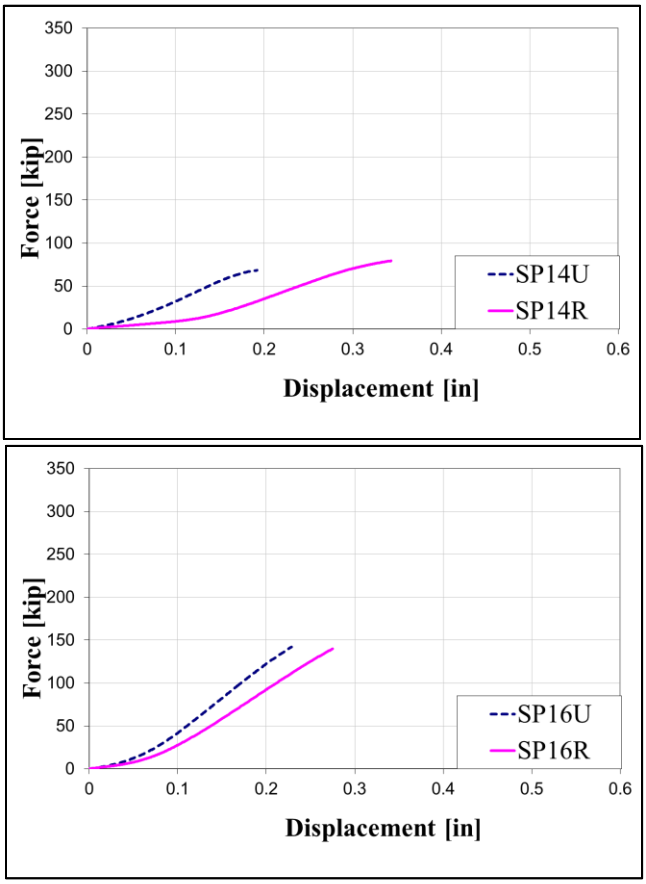


Figure 6. Force-displacement relationship for specimens with nails.

Figure 6 shows two specimens (SP14 and SP16) which used nails instead of the steel drift pin to join the two pieces of wood. The unretrofitted specimens are less stiffer than the retrofitted specimens and the strength was similar. These are analogous results than those obtained in the specimens joined with steel drift pins.

8 CONCLUSIONS

This paper focused on explaining the experiment program developed to evaluate the feasibility of using FRP retrofit technique to restore the flexural capacity of deteriorated bridge timber piles under eccentric loading. A total of 16 pile specimens were used in the study. Each specimen was tested before and after retrofitting with GFRP or CFRP sheets. Different details of the FRP retrofit technique were investigated including applying FRP with and without mortar shell, introducing mortar-filled wedge in the tested specimen prior to wrapping it with FRP to mimic the effect of severe damage, and posting the piles with nails instead of steel drift pins. The test results showed acceptable structural behavior for the specimens retrofitted with GFRP sheets, regardless of the retrofit details adopted in the tests.

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